'EL GERMANIUM DETECTOR TRANSFER STANDARD AT 1.064μm

Alvin L. Rasmussen
Douglas L. Franzen

National Bureau of Standards
U.S. Department of Commerce
Boulder, Colorado 80303

January 1986

NBSIR 85-3041

LOW-LEVEL GERMANIUM DETECTOR TRANSFER STANDARD AT 1.064μm

Alvin L. Rasmussen
Douglas L. Franzen

Electromagnetic Technology Division
Center for Electronics and Electrical Engineering
National Engineering Laboratory
National Bureau of Standards
Boulder, Colorado 80303

January 1986

U.S. DEPARTMENT OF COMMERCE, Malcolm Baldrige, Secretary

NATIONAL BUREAU OF STANDARDS, Ernest Ambler, Director

Contents

Low-Level Germanium Detector Transfer Standard at 1.064 μm

Alvin L. Rasmussen
Douglas L. Franzen

Electromagnetic Technology Division
National Bureau of Standards
Boulder, Colorado 80303

Two germanium PIN photodiodes have been calibrated in the 1 to 250 fJ/cm^2 range with 15 percent uncertainty for 1.064 μm laser pulses of 10 to 100 ns duration. To do these calibrations, we used (1) an acousto-optically modulated cw Nd:YAG laser beam and a silicon PIN photodiode transfer standard to provide low-level laser pulses of known energy and (2) a pulsed 1.06 μm LED beam. A 1 cm^2 collecting lens and a ground-glass diffuser were placed in front of each detector to improve sensitivity and spatial uniformity, respectively. In the future, these detectors may also be useful as transfer standards at wavelengths out to 1.7 μm.

Keywords: beamsplitter attenuator; low-level laser measurements; modulated cw measurement system; 1.064 μm laser pulse measurements; germanium PIN photodiode transfer standard; pulse energy; pulsed 1.06 μm LED measurement system; spatial scanning of germanium photodiode detector

1. Introduction and Background

Because of Nd:YAG laser applications in low-level guidance receivers and range finders, the National Bureau of Standards (NBS) developed APD and PIN silicon photodiode transfer standards [1] to measure low-level peak power and energy, respectively, for 10 to 100 ns duration, 1.064 μm laser pulses at 10 to 15 percent uncertainty. Without a collecting lens, the silicon PIN photodiode transfer standards can measure pulses of about 10^{-14} J/cm^2 to 10^{-11} J/cm^2. Because of continuing interest in low-level measurements and the desire to extend them to longer wavelengths, NBS has developed germanium PIN photodiode transfer standards. At 1.06 μm, the latter are about 10 times more sensitive than the silicon PIN photodiode transfer standards.

In this article, we will describe spatial scanning of the germanium photodiodes, construction of the detection systems, modulation calibrations, and LED calibrations.

2. Spatial Scanning of the Germanium PIN Photodiodes

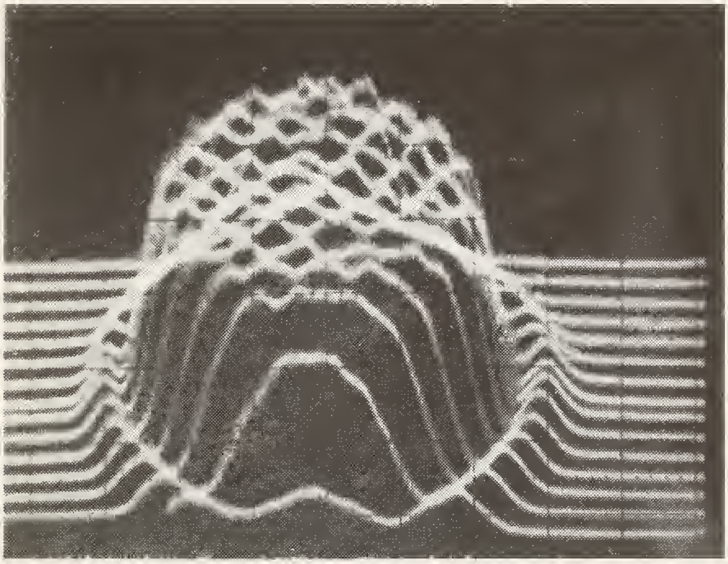
Using a cw 1.064 μm laser beam, we determined the spatial uniformity of the germanium PIN photodiodes with and without a 600 grit, ground-glass diffuser in front of the detector window (figs. 1 and 2). The room in which the measurements took place was almost totally dark. The beam was greatly attenuated, chopped, and focused to a diameter less than 1 mm. The 1/4 cm^2 area (6 mm diameter) germanium photodiode detectors were scanned in the order of 5 min. Detector output was fed into a lock-in amplifier, and the amplifier output was read on an oscilloscope. Scans showed large variations in the spatial uniformity of the diodes when no diffuser was used (figs. 1 and 2). The flat window in front of the diode may have contributed significantly to this nonuniform response. A diffuser in front of the window greatly improves the spatial uniformity of the diode (figs. 1 and 2).

3. Construction of the Detection Systems

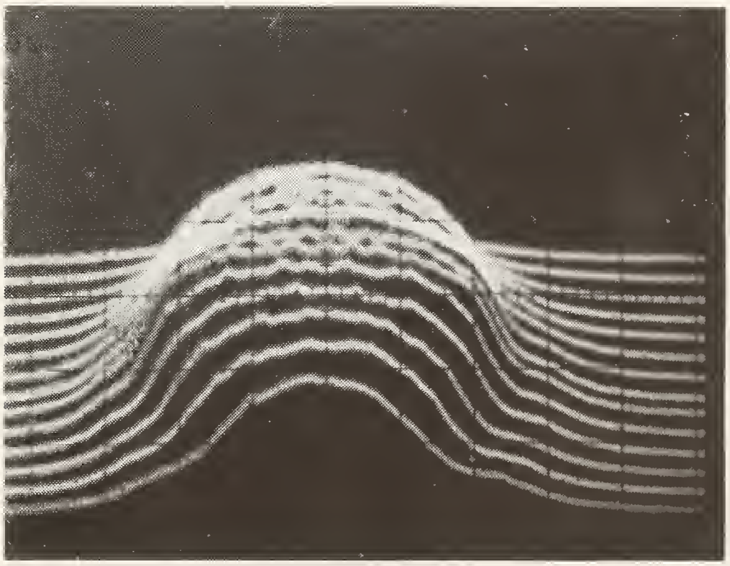
The germanium detection systems were constructed as described below. The detectors were commercial units with the germanium PIN photodiode detector at one end of the Dewar flask and the fill hole for liquid N_2 and electrical connections at the other end. The specifications are given in table 1.

Table 1. Manufacturer's specifications for germanium PIN photodiode detectors.

Operating temperature	77 K
Operating bias	-300 V
Detector area	0.25 cm^2
NEP	$2 \cdot 10^{-14}$ and $1 \cdot 10^{-15}$ W $Hz^{-1/2}$
Responsivity (we integrated the output for pulse energy measurements)	100 V/μW and 5000 V/μW
Time constant	15 μs and 1 to 2 ms
Window	sapphire
Operating position (we used them in a horizontal position)	vertical or horizontal

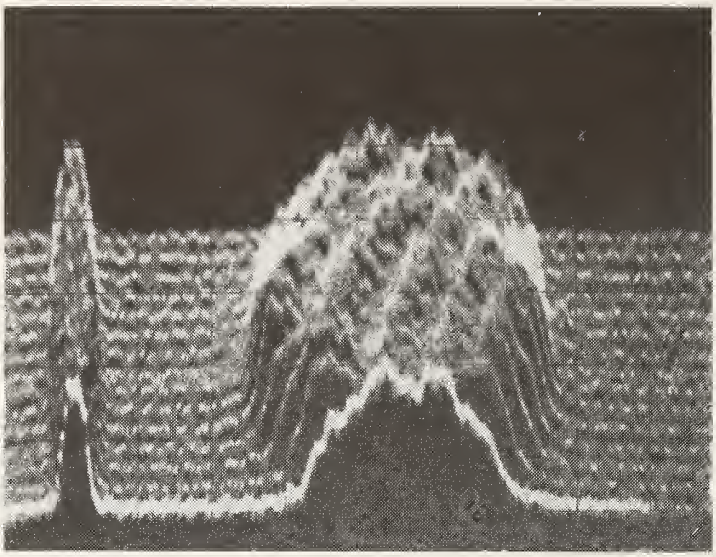


(a)

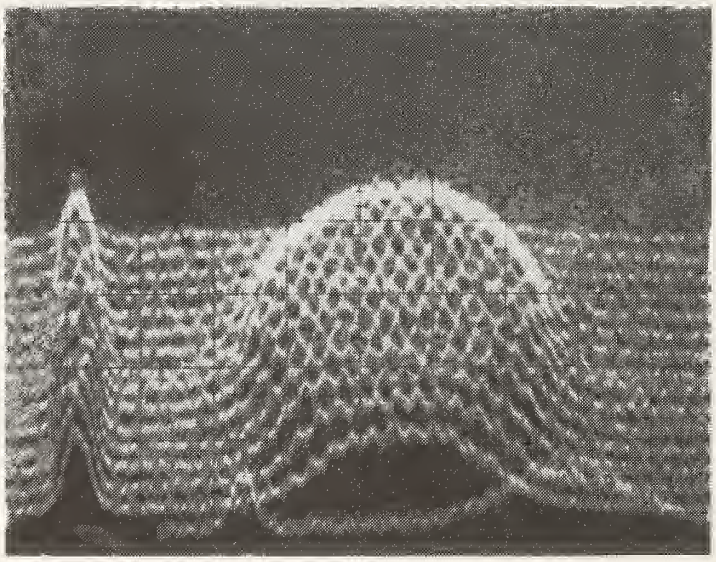


(b)

Figure 1. (a) Spatial uniformity of germanium detector Ge 6-1 at a wavelength of 1.064 μm; (b) same, with ground-glass diffuser.



(a)



(b)

Figure 2. (a) Spatial uniformity of germanium detector Ge 6-2 at a wavelength of 1.064 μm; (b) same, with ground-glass diffuser.

The detectors were each sealed in a portable light-tight enclosure. The entrance includes a 1.00 cm^2 aperture and 5:1 beam reduction collimator. The latter had a narrowband 1.064 μm antireflection coated, positive lens followed by a negative lens. Once inside the box the beam travels about 5 cm and then passes through a unit consisting of a wedge, an aperture, and a diffuser before entering the sapphire window of the detector. The wedge is SF-6 glass with a 1 deg wedge angle. It was to provide a reflected beam for the purpose of pulse shape measurements. The aperture had a 0.4 cm diameter and was parallel to the rear face of the wedge. The diffuser, a quartz glass with a 600 grit ground rear face, was oriented approximately 0 deg to the original beam and was approximately 1/3 cm from the detector window.

4. Modulator System Calibration

The modulator system is a cw Nd:YAG laser beam acousto-optically modulated with a silicon PIN photodiode transfer standard in one of the beams of a beamsplitter attenuator to provide low-level laser pulses of known energy (fig. 3). The beamsplitter attenuator, BA-1, attenuates the beam according to the number of beam reflections between the front and back surfaces of a 2 deg quartz wedge.

To calibrate the germanium detection systems, a silicon PIN photodiode transfer standard in a higher order beam (attenuation about 900) monitors the pulse energy to the germanium detector in a still higher order beam (attenuation about 27,000). Black painted tubes were placed in front of all detectors to reduce the field of view; the room was kept fairly dark. A differential amplifier oscilloscope plug-in was used to read out the germanium detectors. The faster detector, Ge 6-1, was calibrated without problems. The slower detector, Ge 6-2, however, was easily saturated, yielded unsteady output, and could not follow rapid random changes in the laser output. Therefore, another scheme, described in the following section, was devised to calibrate detector Ge 6-2.

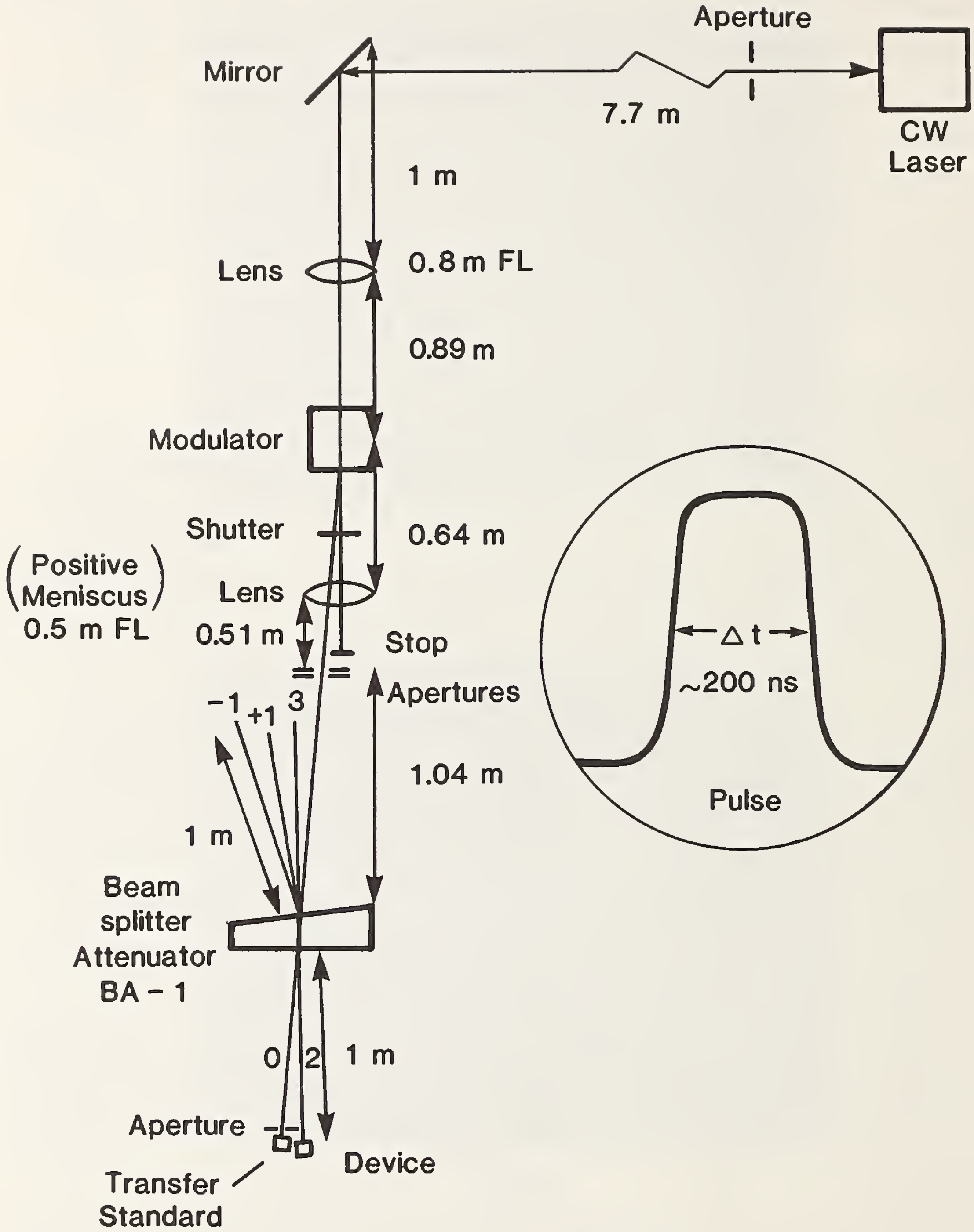


Figure 3. Low-level modulated cw measurement system.

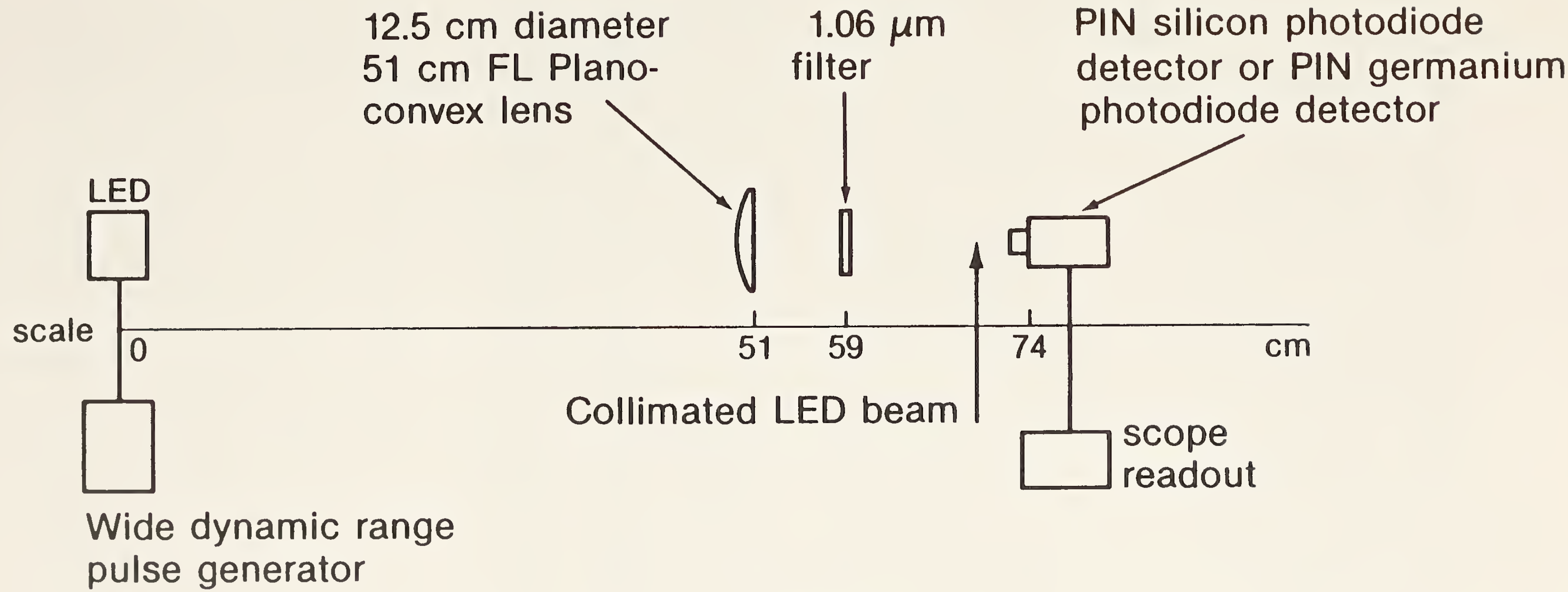


Figure 4. Pulsed LED system for calibrating low-level detectors.

5. LED System Calibration

A pulsed LED system for calibrating low-level detectors (fig. 4) was used to calibrate the Ge 6-2 detector against the Ge 6-1 detector and to measure its linearity. One detector at a time was placed in the very stable LED beam. The LED system generated light pulses at approximately 1.06 μm. The central wavelength and line width of pulses [2] are somewhat different from the Nd:YAG laser. Since the calibration of the silicon PIN photodiode varies rapidly with wavelength, the silicon PIN photodiode could not be used in the LED system to calibrate the germanium detectors. The latter, however, are much less sensitive to changes in wavelength in this range and can be used in the LED system to calibrate similar detectors.

A 12.5 cm diameter planoconvex lens placed about one focal length from the LED collimated the beam. A 10 cm diameter, nominally 1.06 μm, interference filter and a detector followed the lens. The detector output changed negligibly when moved 50 cm along the optical axis of the beam. The beam cross section was uniform over an 8 to 10 cm diameter.

No spectrophotometer was available to evaluate the wavelength response of the 1.06 μm filter. A rough evaluation of the filter was made as described below. The filter was inserted in a low-level beam of the modulated cw system. The filter passed about 70 percent of the 1.064 μm beam. We used the Ge 6-1 detector to measure any difference in calibration of a silicon PIN photodiode between the LED and modulated cw systems. From this difference in calibration and the manufacturer's responsivity-versus-wavelength curve, we estimated the effective wavelength of the LED output to be 1.08 μm.

Applying precisely decreasing steps of current to the LED, we measured the output of the PIN 4-1 silicon transfer standard and the germanium (Ge 6-1 and Ge 6-2) PIN photodiode detectors. For the three detectors, measurement ratios of each step output to the maximum output were within 1 or 2 percent of each other. As each detector in the order of PIN 4-1, Ge 6-1 and Ge 6-2 descended into the noise, measurements were no longer possible. Since PIN 4-1 and Ge 6-1 were linear detectors, Ge 6-2 was also judged to be linear. We used Ge 6-1 to calibrate Ge 6-2. When Ge 6-1 could no longer be used as a transfer standard, we computed the pulse energy into Ge 6-2 from its own calibration.

6. Results

Two germanium PIN photodiodes were calibrated from 1 to 250 fJ/cm^2 with 15 percent uncertainty for 10 to 100 ns duration, 1.06 μm laser pulses (tables 2 and 3). They are portable transfer standards, traceable to the national standard [3] of laser power and energy, and about 10 times more sensitive than the silicon transfer standards at 1.064 μm. The latter systems have 1 cm^2 area. The spectral responsivity of the germanium detectors makes them potentially useful to 1.7 μm.

Table 2. Ge 6-1 and Ge 6-2 germanium PIN photodiode system calibration.*

Detector	Calibration J/V cm^2 †	Number of calibrations (n)	Error in measurement average at 95% Ci (%)	Total estimated error at 95% Ci (%)	Energy range fJ/cm^2 *	Readout range V †	Estimated noise fJ/cm^2 *
Ge 6-1 (817S) at H setting	$5.1 \cdot 10^{-13}$	105	0.4	15.1	2.5-250	0.005-0.5	~±0.2
Ge 6-2 (817L) at H setting	$5.0 \cdot 10^{-13}$	28	0.3	15.4	1-60	0.002-0.1	~±0.08

*Pulses were less than 200 ns at 1.06 μm. Collector areas were for Ge 6-1, A_1 = 0.992 cm^2 and for Ge 6-2, A_2 = 0.998 cm^2.

†Readout TX 7904 oscilloscope [4], +CH, 7A22 plug-in, HF -3 dB point 1 MHz, LF -3 dB point 10 kHz. Measurements made from December 1984 through March 1985.

Table 3. Error budget Ge 6-1 and Ge 6-2.

Source of error	Uncertainty (%)*
PIN 4-3, silicon photodiode transfer standard (traceable to national standards)	8.0
Beamsplitter attenuator (beam ratio = 29.7)	0.7
PIN 4-3 oscilloscope readout	3.0
Ge 6-1 oscilloscope readout	3.0
Precision	
Ge 6-1	0.4
Ge 6-2	0.3
Total error budget**	
Ge 6-1	15.1
Ge 6-2	15.4

* At the 95 percent confidence interval.

** Over half of the error budget comes from the readout used. If a more accurate readout were obtained, the uncertainty could be significantly improved.
In calibrating Ge 6-2, ratios of output readings of Ge 6-1 and Ge 6-2 were used. Readout error was reduced to the measurement precision.

7. References

[1] Sanders, A. A.; Rasmussen, A. L. A system for measuring energy and peak power of low-level 1.064 μm laser pulses. Nat. Bur. Stand. (U.S.) Tech. Note 1058; 1982.

[2] Young, M. The use of LEDs to simulate weak YAG-laser beams. Nat. Bur. Stand. (U.S.) Tech. Note 1031; 1981.

[3] Franzen, D. L.; Schmidt, L. B. Absolute reference calorimeter for measuring high power laser pulses. Appl. Opt. 15: 3115; 1976 December.

[4] Certain trade names are used in this report in order to specify the experimental conditions used in obtaining the reported data. Mention of these products does not imply recommendation or endorsement by the National Bureau of Standards, nor does it imply that the materials or equipment identified are necessarily the best available for the purpose.

NBS-114A (REV. 2-8C)

U.S. DEPT. OF COMM. BIBLIOGRAPHIC DATA SHEET (See instructions)	1. PUBLICATION OR REPORT NO. NBSIR 85-3041	2. Performing Organ. Report No.	3. Publication Date January 1986

4. TITLE AND SUBTITLE

Low-Level Germanium Detector Transfer Standard at 1064 m

5. AUTHOR(S)

Alvin L. Rasmussen and Douglas L. Franzen

6. PERFORMING ORGANIZATION (If joint or other than NBS, see instructions)

NATIONAL BUREAU OF STANDARDS
DEPARTMENT OF COMMERCE
WASHINGTON, D.C. 20234

7. Contract/Grant No.

8. Type of Report & Period Covered

9. SPONSORING ORGANIZATION NAME AND COMPLETE ADDRESS (Street, City, State, ZIP)

Department of Defense
Calibration Coordination Group
Aerospace Guidance and Metrology Center
Newark Air Force Station, Ohio

10. SUPPLEMENTARY NOTES

☐ Document describes a computer program; SF-185, FIPS Software Summary, is attached.

11. ABSTRACT (A 200-word or less factual summary of most significant information. If document includes a significant bibliography or literature survey, mention it here)

Two germanium PIN photodiodes have been calibrated in the 1 to 250 fj/cm^2 range with 15 percent uncertainty for 1.064 μm laser pulses of 10 to 100 ns duration. To do these calibrations, we used (1) an acousto-optically modulated cw Nd:YAG laser beam and a silicon PIN photodiode transfer standard to provide low-level laser pulses of known energy and (2) a pulsed 106 μm LED beam. A 1 cm^2 collecting lens and a ground-glass diffuser were placed in front of each detector to improve sensitivity and spatial uniformity, respectively. In the future, these detectors may also be useful as transfer standards at wavelengths out to 1.7 μm.

12. KEY WORDS (Six to twelve entries; alphabetical order; capitalize only proper names; and separate key words by semicolons)

beamsplitter attenuator; low-level laser measurements; modulated cw measurement system; 1.064 μm laser pulse measurements; germanium PIN photodiode transfer standard; pulse energy; pulsed 1.06 μm LED measurement system; spatial scanning of germanium photodiode

13. AVAILABILITY

[X] Unlimited

☐ For Official Distribution. Do Not Release to NTIS

☐ Order From Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402.

[X] Order From National Technical Information Service (NTIS), Springfield, VA. 22161

14. NO. OF PRINTED PAGES

16

15. Price